

The Great Basin Naturalist

PUBLISHED AT PROVO, UTAH, BY
BRIGHAM YOUNG UNIVERSITY

ISSN 0017-3614

VOLUME 46

31 January 1986

No. 1

DYNAMIC LANDFORMS AND PLANT COMMUNITIES IN A PLUVIAL LAKE BASIN

James A. Young¹, Raymond A. Evans¹, Bruce A. Roundy², and John A. Brown³

ABSTRACT.—Mapping units were developed based on landform, soils, and plant communities for the 40,000 ha of salt desert vegetation located below the maximum level of pluvial Lake Gilbert in Grass Valley, Nevada. Lake plain, beach, and bar features of the pluvial lake provide the dominant landforms. Fine textured lake sediments have produced salt- and Na-affected soils. The distribution and structure of plant communities are related to depth of the groundwater table, fluctuations in this depth, and the salt content of the groundwater. Wind and water erosion combine to continually evolve new environments for colonization by plants in this ecosystem.

The structure and association of plant communities occupying basins in western North America that were formerly inundated by pluvial lakes has long been of interest to ecologists (Shantz and Piemeisel 1940, see West 1983 for description of ecosystems). The progressively finer textured soils from the edge of the basins and increasing concentration of soluble salts that formed as the lakes dried offered the potential of relating plant communities to soils, and especially to the salt content of soils (Kearney et al. 1914, Clements 1920, Billings 1945). Such salt-plant community orientations are complicated by the extreme aridity of many pluvial lake basins. In the Great Basin of the western United States, the entire province is located in the rain shadow of the Sierra Nevada and the Cascade Mountains. In addition, the mountains that rim many of the subbasins range from 2,150 to more than 3,000 m in elevation, casting their own rain shadows across the arid bottoms of the valleys (Houghton et al. 1975). The result is that the natural vegetation of the valley

bottoms may reflect lack of atmospheric precipitation as much as the reduced osmotic potential of soil water solutions (Billings 1949).

The concept of pluvial basins containing concentric rings of soils with increasing salt content helps explain the distribution of many salt desert plant communities (Flowers 1934). The occurrence of other plant communities such as those dominated by *Ceratoides lanata* or *Atriplex confertifolia* is not associated with specific soil features (Gates et al. 1956). The distribution of *Atriplex nuttallii* on soils from low to high salinity is a good example of ecotypic differences within a species in relation to salt tolerance (Goodman 1973). Genetic differences must be considered when relating plant distribution to edaphic factors in the salt desert. Stutz (1978) has presented evidence that the new habitats provided by the drying of pluvial lake basins provide space for the explosive evolution of perennial species of *Atriplex*. Some of the landscape occupied by species of *Atriplex* exist in complex polyploid

¹U. S. Department of Agriculture, Agricultural Research Service, 920 Valley Road, Reno, Nevada 89512.

²Formerly with Agric. Res. Ser., currently at University of Arizona, Tucson.

³Formerly research hydrologist, University of Nevada, Reno. Deceased.

⁴Plant names based on Cronquist et al. (1972) and Munz and Keck (1968). Plant specimens on file USDA/ARS Herbarium, Reno, Nevada.

series. These desert landscapes dominated by woody chenopods apparently have limited regeneration and appear, superficially, to be composed of nearly identical individuals. According to Stutz's hypothesis, the endless sameness of woody chenopods is a mirage concealing dynamic evolutionary processes.

Distinct patterns of vegetation on pluvial lake sediments were postulated by Miller et al. (1982) to be due to differences in soil-water-plant relations. Differences were caused either by the depth to groundwater or from differences in water-retention capacities of soils deriving water only from precipitation.

In a recent review, West (1982) logically refuted the stereotype concept that salt desert shrubs exist in spatial harmony in equilibrium with the very limited environmental potential of their environment. In fact, chenopod shrubs tend to be grouped in competitive clumps where litter-fall on coppice mounds has enhanced the potential of seedbeds to support germination and seedling establishment (Charley and West 1975). The chance recruitment of seedlings into these communities may be conditioned by erratically occurring episodic climatic events (West 1979).

Due to the lack of atmospheric precipitation and subsequent runoff water, many of the lower pluvial lake basin environments appear remarkably stable once the soil surface becomes stabilized by vegetation and desert pavement formed by wind erosion. We propose that much of this apparent stability is as much a mirage as the genetic stability of the shrub populations. The pluvial lakes shaped the basin bottoms with currents and waves. Sedimentations in the deep water areas were usually very fine textured. Lowering the water level in the lakes lowered the base level of the attendant streams. Landforms and hydrologic processes in and surrounding pluvial lake basins are striving toward stability in a radically different environment. Our purpose was to characterize the major plant communities of a pluvial lake basin in relation to landforms and soils.

METHODS

The study was conducted in Grass Valley, Nevada, 39°52' latitude, 116°37' longitude. Grass Valley is a closed basin with a watershed

basin of 1,500 km². During the Pleistocene, the basin contained pluvial Lake Gilbert, which had a surface area of 400 km² (Mifflin and Wheat 1979). The maximum level of Lake Gilbert was 1,766 m. The bottom of the basin is now 1,728 m. Some authorities (e.g., Hubbs and Miller 1945) consider that Lake Gilbert overflowed at its maximum level and formed part of the Lake Lahontan systems. Mifflin and Wheat (1979) point out that the maximum beach ridge of Lake Gilbert is 39 m below the supposed outlet pass.

Color infrared aerial photographs, scale 1:15840, were used for identifying landforms and drainage patterns; plant communities were mapped on 1:62500 U.S. Geological Survey maps. Shrub vegetation in each community was sampled with 10 plots, each 10 m² in area. The plots were randomly located along paced transects from a starting point selected on the aerial photographs. The projected crown cover, height, and density of shrubs were recorded by species. The herbaceous vegetation and cryptogamic soil crust (Anderson 1978) were sampled for frequency and cover with four replications of 100 step points using the procedures described by Evans and Love (1957).

Soil profiles were excavated in each major vegetation assemblage. Profiles were described according to the Soil Survey Manual (Anonymous 1951). Soils were classified according to the U.S. Soil Conservation Service system (Anonymous 1975). Soil samples were analyzed for percent gravel by straining through a 2-mm screen; percent sand, silt, and clay were determined using the Bouyocus (1962) method. Electrical conductivity of the saturated soil paste extract was determined by a conductivity meter (Black 1965).

In 1981 a network of shallow wells was installed in three transects from the alluvial fans across the lake plain to the central playa. The wells were distributed along the transects on the basis of plant communities and landforms. The wells were drilled to 4.6 m, with a 10-cm rotary drill and cased with perforated plastic pipe 3.75 cm in diameter, and gravel was packed around the casing. The depth of the water table was measured periodically, and samples were collected and analyzed for electrical conductivity and temperature. A portable signal-enhanced seismograph was used

TABLE 1. Landforms, vegetation, soil texture, percentage of total area, and number of stands sampled for the land area below the maximum level of pluvial Lake Gilbert, Grass Valley, Nevada. Map units refer to Figure 1.

Landform Major subunit	Map unit	Vegetation Dominant species	Soil texture	Area ha	Percentage of total	Number of stands
PLAYA						
Playa	1	None	Clay	6040	15.0	64
Wet depression	1a	None	Clay	10	—	3
Hummocks	1b	<i>Allenrolfoa occidentalis</i>	Silty clay loam	10	—	3
Mobile dunes	2	<i>Sarcobatus vermiculatus</i>	Clay	120	0.3	12
Haystack dunes	2a	<i>Sarcobatus vermiculatus</i>	Clay	10	—	6
Recent Holocene beach	2b	<i>Kochia americana</i>	Clay	10	—	2
				6200	15.4	
LAKE PLAIN						
Older Holocene beach	3	<i>Sarcobatus vermiculatus</i>	Silty clay loam	2660	7.0	3
Stable dunes	4	<i>Sarcobatus vermiculatus</i>	Silt loam	160	0.4	3
Clay dunes	5	<i>Sarcobatus vermiculatus</i>	Clay	380	0.9	11
Dune basins	6	<i>Distichlis/Sporobolus</i>	Clay	50	1.4	2
Lake plain	7	<i>Chrysothamnus-Sarcobatus-Artemisia/Elymus</i>	Silty clay loam	2130	5.3	17
	8	<i>Sarcobatus/Distichlis</i>	Silty clay loam	90	0.2	5
	9	<i>Sarcobatus-Atriplex confertifolia</i>	Silty clay loam	2160	5.4	7
	10	<i>Chrysothamnus albidus/Puccinella</i>	Silty clay	10	—	3
	11	<i>Atriplex nuttallii</i>	Silty clay loam	30	0.1	3
				8070	20.2	
Thermal springs	12	<i>Distichlis/Juncas</i>	Clay	460	1.1	2
Barrier beach	13	<i>Sarcobatus vermiculatus</i>	Clay	820	2.0	2
	14	<i>Sarcobatus/Kochia</i>	Clay loam	190	0.5	2
	15	<i>Atriplex confertifolia</i>	Silty clay loam	116	0.3	2
				1120	2.8	
Lagoon	16	<i>Allenrolfoa occidentalis</i>	Clay	1470	3.7	4
	17	<i>Chrysothamnus nauseosus/Distichlis</i>	Silty clay loam	990	2.5	3
				2460	6.2	
Sand dunes	18	<i>Tetradymia/Grayia</i>	Sand	130	0.3	2
Alluvial fans	19	<i>Artemisia tridentata</i>	Loam to gravelly sandy loam	7350	18.3	12
	20	<i>Atriplex confertifolia</i>	Silty clay loam to gravelly sandy loam	13760	34.3	21
				21110	52.6	
Bars	21	<i>Atriplex confertifolia</i>	Gravelly sandy	370	0.9	3
Lagoons (upland)	22	<i>Sarcobatus vermiculatus</i>	Silt loam	130	0.3	3
	23	<i>Atriplex confertifolia</i>	Silt loam	60	0.2	3
				190	0.5	

in the summer of 1981 to determine depth to the water table at 35 locations in the valley. The seismographic data were calibrated against wells with known water tables.

caused by several interacting variables. Some divisions are obvious, but others are arbitrary because of the limits of our current knowledge of these environments.

RESULTS

Plant Communities of the Playa

The area surveyed was approximately 40,110 ha (Table 1). We established a total of 23 map units (Fig. 1, Table 1). Most of these landform-vegetation-soil map units represent ranges in more or less continuous variation

The surface of the Grass Valley playa is usually free of vegetation (Fig. 2). Obviously the salt content of the surface soils of the playa are limiting to plant growth, but occasional prolonged periods of flooding may be the lim-

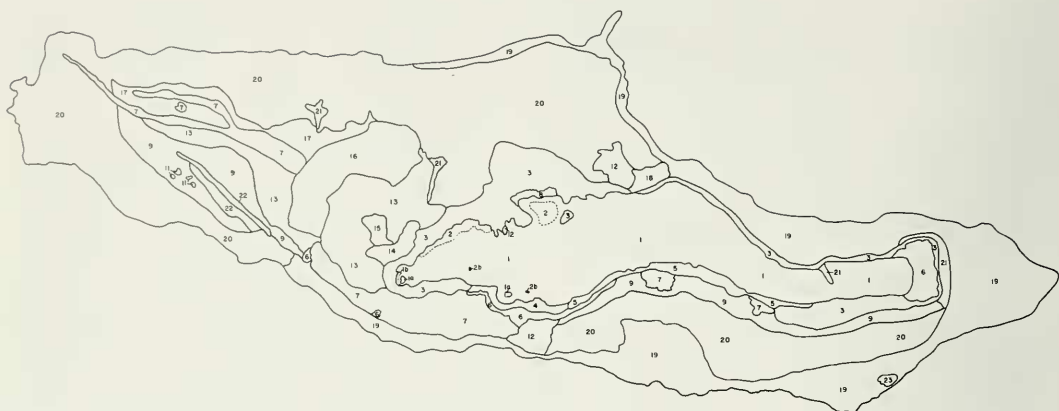


Fig. 1. Distribution of map units for pluvial Lake Gilbert below the maximum lake level. Units based on landform, soils, and vegetation. *Area* designation (based on dominant plant species) and area of map units given in Table 1.

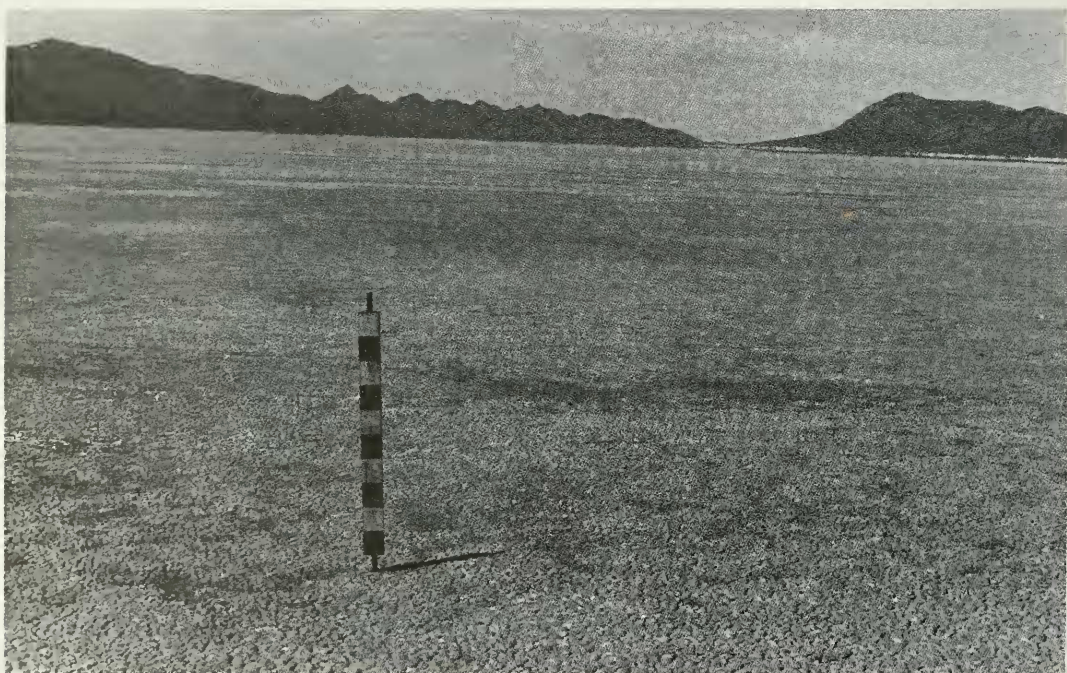


Fig. 2. Grass Valley playas, viewed from a central location looking north. Hot Springs Point (2,300 m), Sawtooth Mountains (2,230 m), Cortez Pass (1,805 m), and Mount Tenabo (2,820 m) on skyline in background from left to right. Note typical polygonal cracking of playa surface. Range pole 1 m divided into dm.

iting factor for the most extreme halophytes. Flooding is probably the factor limiting the

spread of rhizomes of the grass *Distichlis spicata* var. *stricta*.⁴ Rhizomes, several meters in



Fig. 3. Wet depressions on margin of playa with effervescence of salt crystals. Middle distance shows group of puff dunes. Holocene beach with scattered plants of *Atriplex nuttallii*. Range pole 1 m divided in dm.

length, can be observed extending down eroded slopes to the playa surface.

Very occasionally, a sparse cover of summer-annual herbaceous vegetation is found on the margin of the playa. *Suaeda occidentalis*, *Atriplex truncata*, and *Halogeton glomeratus* form these communities.

The depth and electrical conductivity of groundwater on the playa varied greatly, depending on the sampling location and season. In the fall, when the playa was dry, the water table in observation wells ranged from 1.5 to 1.8 m below the playa surface. Electrical conductivity of water from the wells ranged from 34 to 105 dS m^{-1} . In the spring, when the groundwater reached the surface of the playa, electrical conductivity of the water dropped to 3 to 10 dS m^{-1} .

Portions of the playa were surveyed and brass plaques were mounted on 3.75-cm-diameter galvanized steel pipe to mark section corners in 1917–1918. By 1979 the pipe supports were faint discolorations in the playa soil profiles. Wooden fence posts planted during the same time period now have bases

swollen by salt crystallization to three times their current aerial diameters.

Hummocks.—The wet depressions on the margins are free of vegetation (Fig. 3), but the margins of these depressions are partially ringed with elongated hummocks scarcely 25 cm above the playa surface. The mounds are salt encrusted, and the unwary playa hiker who steps on the mounds for footing in the slimy-slick soils of the wet depression is greeted by a puff of salts that instantly can be tasted. Despite the salinity of the mounds, they are densely vegetated with clumps of *Allenrolfea occidentalis* (Fig. 4). The electrical conductivity of extract from the surface soils of the wet depressions reached values of 400 dS m^{-1} and averaged 34 dS m^{-1} . The texture of the soils of the wet depressions consists of at least two-thirds clay-sized particles, whereas the texture of the mounds is at least two-thirds silt-sized particles.

These mounds may form during drying cycles on the playa when the crystallization of salts around the wet depressions causes miniature salt domes to form. The domes trap



Fig. 4. Small puff dune with *Allenrolfea occidentalis*. Range pole 1 m divided in dm.

silts in their irregular surface topographies and eventually rise high enough above the playa surface to permit the establishment of *Allenrolfea* plants. The silt particles are highly permeable compared to the clays of the playa and therefore may be readily leached of soluble salts.

Mobile Dunes.—Mobile dunes are found on the western margin of the playa, especially where ephemeral streams dump bed loads onto the playa (Fig. 2). These dunes are from 1.0 to 2.0 m in height and are egg shaped in outline (Fig. 5). The pointed end of the dunes is oriented toward the southwest.

The dunes are vegetated with clumps of *Sarcobatus vermiculatus*, a highly variable species. Juvenile plants have a distinct fleshy leaf morphology. Plants growing on upland sites where the groundwater table is not close to the surface are small, stunted, and gray in color. This form is classified as *S. vermiculatus* var. *baileyi*, or it is sometimes raised to the species level (*S. baileyi*).

On the mobile dunes the *Sarcobatus* plants are highly polymorphic. The west-southwest portions of the dunes are usually bare. During

dry periods electrical conductivity of the bare soils may reach 250 dS m^{-1} . The tops of the dunes are covered with dense patches of dwarfed *Sarcobatus* stems scarcely 2 dm tall. Electrical conductivities of the soils under the dwarf shrubs may reach from 60 to 85 dS m^{-1} . The east slopes of the dunes support relatively sparse stands of *Sarcobatus* plants, which reach a meter or more in height. Maximum electrical conductivity of soils on the east slope seldom exceeds from 25 to 40 dS m^{-1} . The *Sarcobatus* plants eventually die and the largely clay textured dunes melt away from the skeletons of crowns and roots. Each dune is apparently vegetated with a single clone of *Sarcobatus*.

Haystack Dunes.—Haystack dunes are sparingly distributed along the southeastern margin of the playa, opposite the wave cut escarpment. These dunes range to 7.5 m in height, the tallest being higher than the adjacent lake plain. The east slopes of these large dunes have sparse stands of *Sarcobatus* plants.

Recent Holocene Beach.—This landform is only preserved in discontinuous stretches

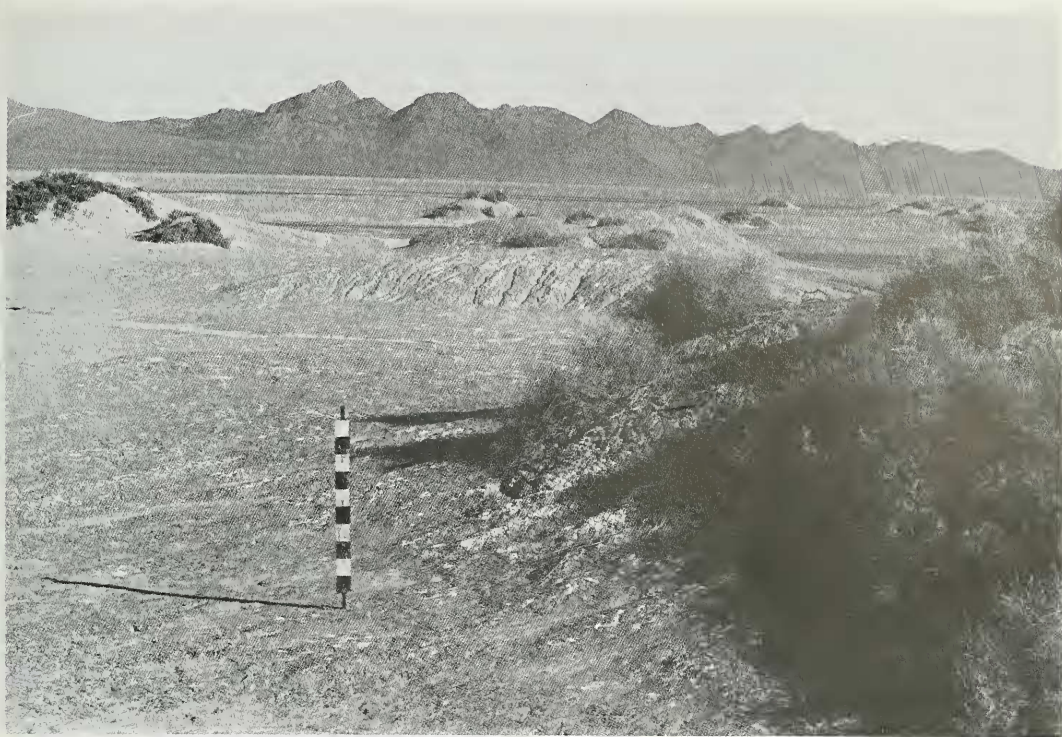


Fig. 5. Mobile dunes vegetated with *Sarcobatus vermiculatus* plants. West side of dunes are largely bare with dwarf plant on top and 1-m tall plants on the east side. If the clones of *Sarcobatus* die, the largely clay-textured dunes melt away (rilled dune in middle distance) and erode across the playa. Range pole 1 m divided in dm.

around the margins of the playa. It apparently represents some recent rise of the lake of sufficient duration to erode a definite beach into the escarpment of the surrounding lake plain. The discontinuous nature of this beach provides evidence of the highly erodible nature of the interface between playa and lake plain.

Vegetating these fragments of Holocene beach is a relatively dense overstory of shrubs (density 0.9 plants per per m², cover 8%) consisting of *S. vermiculatus*, *Atriplex confertifolia*, *A. nuttallii*, and *Kochia americana*. Virtually, the only herbaceous species in these communities is *Thelypodium flexuosum*.

Plant Communities of the Lake Plain

Older Holocene Beach.—This is the largest mapping unit of the lake plain associated landforms, constituting 7% of the area of the total pluvial lake basin (Table 1). This landform is located about 2 m higher than the recent Holocene beach that incompletely surrounds the current playa. The general topography is nearly flat from a prominent beach

ridge located at 1,730 m elevation to the escarpment at the playa edge (Fig. 6). On the southeast margin of the playa, stable dunes cover the older Holocene beach, and on the northeast side of the playa, clay dunes interrupt drainage to the playa, forming dune basins on the older Holocene beach surface. Occasional drainage channels have eroded channels into the lake plain, creating miniature badland topographies. The microtopography consists of coppice dunes occurring around shrubs and averaging from 20 to 30 cm in height. The coppice dunes support thin, ragged-edge microphytic crusts. The interspace between shrubs is usually bare of vegetation and microphytes.

Soils of the lake plain largely belong to the order Inceptisols (Anonymous 1975). A typical soil for the older Holocene beach would be classified as a fine, montmorillonitic (calcareous), mesic Aeric Halaquept. A typical profile consists of a dark, grayish brown salt- and sodium-affected silty clay surface horizon, over a thick (2 m) light gray lacustrine clay



Fig. 6. *Sarcobatus vermiculatus*-dominated plant community located on older Holocene beach on lake plain.

horizon. Below this layer iron mottles are common. Sodium absorption ratios of these soils are 45 or greater, with average electrical conductivity of the saturation extract of 8 to 12 dS m^{-1} . In the upper 30 cm, the predominant salts are sodium chloride and sodium sulfate (Roundy 1984). Salt concentrations of the surface soil decrease due to leaching by winter and spring precipitation and increase with the lack of precipitation in the summer (Roundy et al. 1983).

The depth of the water table on the older Holocene beaches averages 3.2 m during dry periods and 2.1 m in the spring. However, the amount of variation measured was highly dependent on location. Apparently the nature of the watershed and alluvial fan at the mouth of the watershed influences the groundwater on the lake plain adjacent to the alluvial fan. Snowmelt in surrounding mountains causes ephemeral streams to flow on the mountain escarpment in May and early June. As the water leaves the pediment surface, it disappears on the relatively coarse alluvial fans. The water moving down through the fans apparently strikes buried, fine-textured lacustrine

deposits from previous high rises of the lake. Lateral movement of groundwater occurs with discharge in springs or seeps where past wave action has truncated alluvial fans. There is a delay of a month to six weeks between the water disappearing at the mouths of canyons along the mountain escarpment and rising groundwater levels on the lake plain. Below some alluvial fans, even if they were deposited at the mouths of large watersheds, the groundwater level on the lake plain does not vary.

Similar relationships were apparent for soluble salt content of the groundwater. In areas where the water table varied, electrical conductivity of water from the wells dropped as the water table rose and increased as the water table dropped. Where the water table remained stationary, electrical conductivity of the water was very constant.

The plant communities of the older Holocene beach are dominated by *Sarcobatus vermiculatus* shrubs with varying amounts of *Atriplex confertifolia* (Fig. 3). Cover of both species of shrubs was only 12% (Table 2). Only six herbaceous species were recorded in the

understory (Table 3). A Cruciferae, *Thelypodium flexuosum*, was the most frequent herbaceous species encountered.

Atriplex confertifolia tended to occur in relatively pure stands within a matrix of *S. vermiculatus*. The *A. confertifolia*-dominated areas had deeper water tables. *Sarcobatus vermiculatus* is a pronounced phreatophyte with reported rooting to water tables at depths of 7.5 m (White 1932). However, the very low permeability of the clay soils, coupled with the scant atmospheric precipitation associated with the central basin locations, may never result in soil wetting to the water table to permit contact of *S. vermiculatus* roots with the groundwater fringe.

Stable Dunes.—Floristically and physiognomically, the plant communities of the stable dunes are very similar to those of the older Holocene beach. The soil of the stable dunes is classified as a coarse-silty, mixed (calcareous), mesic, Aquic Durorthidic Torriorthent of the order Entisol. The soils are very deep and moderately well drained because of the relatively coarse texture. Typically the surface layer is light gray silt. The underlying material to a depth of 2 m is light brownish gray and light gray stratified and very fine sandy loam and silt loam with discontinuous weak silicon concentration in the upper part. Despite the quite different soil and a generally greater depth to the groundwater table, only the shrub *Grayia spinosa* was added to the plant communities of the stable dunes compared to the older Holocene beaches of the lake plain (Table 2).

Clay Dunes.—With only 8% plant cover, there is little vegetation on the clay dunes (Table 2 and 3). The microdrainages and valleys among the dunes are occupied by flows of salt crystals that are apparent after a rain. Vegetation is generally restricted to the top and east side of the dunes.

Dune Basins.—The dunes, either stabilized or clay, interrupt drainage from the lake plain to the playa. In wet years ephemeral lakes form in the basins (Fig. 7). The typical soils of these basins are classified as fine silty, mixed (calcareous) mesic Aeric Fluvaquents. These soils range from slightly to strongly saline. The slightly saline soils are in the lowest depressions that are subject to spring ponding. The soils are very deep and poorly

drained. Typically the surface layer is light gray, strongly salt- and sodium-affected clay loam.

Sampling the observation wells indicated that the water table depth under this landform ranges from 0.5 to 1.0 m below the soil surface. The electrical conductivity of the water ranged from 0.8 to 1.0 dS m⁻¹.

Repeated flooding limited shrubs in the dune basin community to occasional plants of *Chrysothamnus nauseosus* ssp. *consimilis*, but a total of 27 herbaceous species was recorded in the basins (Tables 2 and 3). *Distichlis spicata* var. *stricta* was the most frequent herbaceous species.

Lake Plain.—The lake plain itself accounts for more than 10% of the basin below the maximum level of the pluvial lake basin. Generally the lake plain is physically positioned above the offshore bar that forms the upper boundary of the older Holocene beach (1,730 m elevation) and a prominent beach that truncates alluvial fans at 1,740 m elevation. The elevations are from the top of one bar to the top of the other bar. Once the plunge pit behind the bottom bar is passed, the lake plain is nearly flat until the 1,740 m bar is reached. The lake plain is not distributed symmetrically in the basin (Fig. 1). Most of the lake plain is located between the southeastern margin of the playa and the wave-truncated alluvial fans at the base of the mountain escarpment. On the northwest margin of the playa, the playa extends to the alluvial fans with no lake plain.

The genesis of the soils of the lake plain apparently combines: (a) periods of relatively deep water flooding with deposition of fine-textured lacustrine sediments; (b) recurring periods of lake desiccation with aeolian erosion and deposition, coupled with alluvial fan encroachment onto the plain; and (c) recurrent flooding with truncation of the alluvial fans and subsequent incorporation of alluvial material into the lacustrine sediment by wave and current action.

Such complex soil formation factors produce a range of soil morphologies depending on the volume of material, the physical and chemical nature of the inputs from alluvial fans, and the physical position in the pluvial lake basin. A typical soil for the bulk of the lake plain above the older Holocene beach

TABLE 2. Density per m² and projected cover of shrub species in plant communities (mapping unit number) of the lake plain and associated landforms.

	Landform, plant community, density, and cover							
	Older Holocene beach (3)		Stable dunes (4)		Parma dunes (5)		Dune basins (6)	
	Density per m ²	Cover %	Density per m ²	Cover %	Density per m ²	Cover %	Density per m ²	Cover %
CHENOPODIACEAE								
<i>Atriplex confertifolia</i>	0.2	2.0						
<i>Grayia spinosa</i>			.1	0.2				
<i>Sarcobatus vermiculatus</i>	0.8	10.0	1.1	14.0	0.6	4.0		
COMPOSITAE								
<i>Artemisia tridentata</i> ssp. <i>tridentata</i>								
<i>Chrysothamnus nauseosus</i> ssp. <i>consimilis</i>							0.3	0.2
<i>Chrysothamnus albidus</i>								
Totals	1.0	12.0	1.2	14.2	0.6	4.0	0.3	2.0

TABLE 3. Frequency (%) and total cover of herbaceous species in plant communities (mapping unit numbers) of the lake plain and associated landforms.*

	Older Holocene beach (3)		Stable dunes (4)		Parma dunes (5)		Dune basins (6)	
	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover
	%	%	%	%	%	%	%	%
CAPRIFOLIACEAE								
<i>Cleonea plocosperma</i>								1
CHENOPODIACEAE								
<i>Atriplex truncata</i>	2							2
<i>Halogeton glomeratus</i>	2		2					T
<i>Monolepis nuttalliana</i>								T
<i>Nitrophilia occidentalis</i>								3
<i>Salsola iberica</i>	4							
COMPOSITAE								
<i>Aster occidentalis</i>								T
<i>Crepis runcinata</i>								2
<i>Haplopappus lanceolatus</i>								T
<i>Haplopappus uniflorus</i>								1
<i>Hymenoxys lemmonii</i>								1
<i>Solidago spectabilis</i>								T
<i>Taraxacum officinale</i>								T
CRUCIFERAE								
<i>Capsella bursa-pastoris</i>								
<i>Descurinia sophia</i>								
<i>Lepidium perforiatum</i>	4		2					6
<i>Thelypodium sagittatum</i>								T
<i>Thelypodium flexuosum</i>	86		92		54			
GRAMINAEAE								
<i>Distichlis spicata</i> var. <i>stricta</i>	2		4		46			54
<i>Elymus cinereus</i>								3
<i>Elymus triticoides</i>								1
<i>Hordeum pusillum</i>								1
<i>Muhlenbergia rohardsonis</i>								2
<i>Puccinellia airoides</i>								5
<i>Puccinellia lemmonii</i>								2
<i>Sitanion hystrix</i>								
<i>Spartina gracilis</i>								T
<i>Sporobolus airoides</i>								8
JUNCAGINACEAE								
<i>Triglochin maritima</i>								1
PLANTAGINACEAE								
<i>Plantago eripoda</i>								1
ROSACEAE								
<i>Potentilla anserina</i>								1
<i>Potentilla pectinisecta</i>								4
<i>Ivesia kingii</i>								2
	7		9		4			86

Lake plain

<i>Chrysothamnus-sarcobatus/ Artemisia-Elymus</i> (7)		<i>Sarcobatus/ Distichlis</i> (8)		<i>Sarcobatus/Atriplex</i> (9)		<i>Chrysothamnus/(10) Puccinella</i>		<i>Distichlis</i> (11)	
Density per m ²	Cover %	Density per m ²	Cover %	Density per m ²	Cover %	Density per m ²	Cover %	Density per m ²	Cover %
				1.1	9.2				
0.2	2.0	1.0	16.0	.6	3.0				
1.0	15.1								
.4	4.0	0.2	3.0					0.3	3.0
1.6	21.1	1.2	19.0	1.7	12.2	0.4	3.0	0.3	3.0
						0.4	3.0		

Lake plain

<i>Chrysothamnus-Sarcobatus-(7) Artemisia/Elymus</i>		<i>Sarcobatus/(8) Distichlis</i>		<i>Sarcobatus-(9) Atriplex</i>		<i>Chrysothamnus/(10) Puccinella</i>		<i>Distichlis</i> (11)	
Frequency %	Cover	Frequency %	Cover	Frequency %	Cover	Frequency %	Cover	Frequency %	Cover
T									
T		2		5					
T									
		1				2		1	
T									
									T
									3
									T
									T
									1
									T
1									
3				6					
8		85				8		77	
72								2	
								1	
		2				36			
						48		12	
16									
									T
									1
									2
									T
									T
16		49		6		11		74	

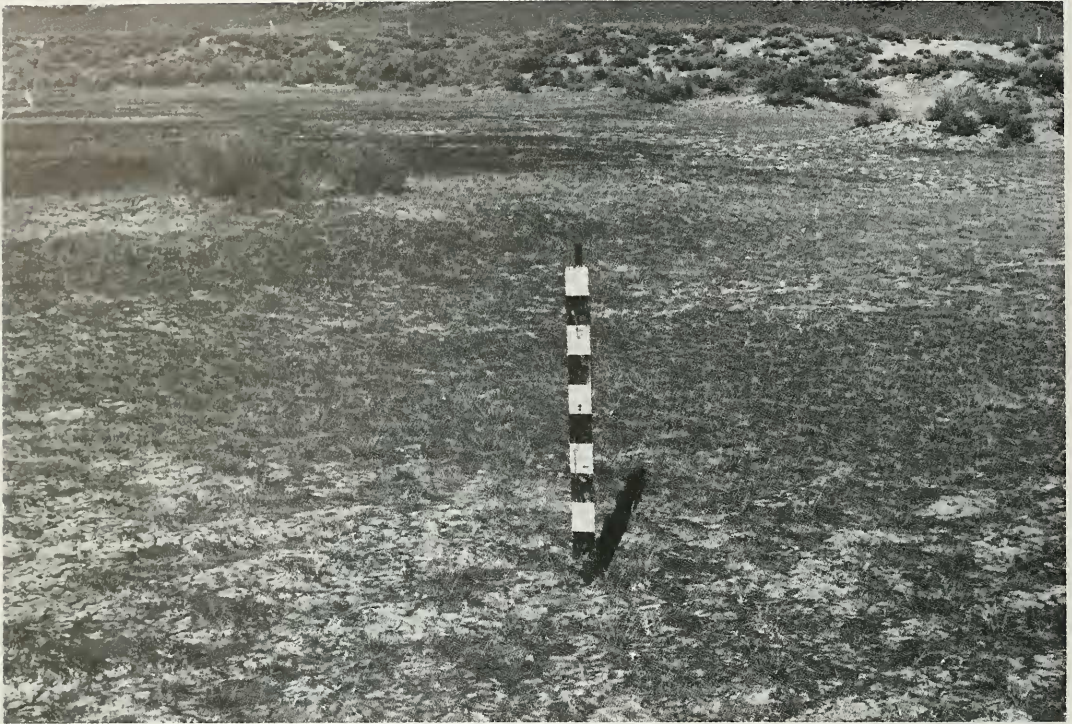


Fig. 7. Dune basin with fairly dense ground cover of *Distichlis spicata* var. *stricta*. In background stabilized dunes with *Sarcobatus vermiculatus* shrubs.

would be classified as a mixed (calcareous), mesic family of Aquic Durorthidic Torriorthent. Typically the surface horizon is pale brown and sodium-affected (sodium absorption ratio >40) silt loam about 10 cm thick. The upper 50 cm of the underlying material is pale brown silt loam that is weakly silicon-concentrated in the lower part. This horizon rests upon at least 2 m of light gray to yellow clay.

The above soil is associated with a complex plant community that combines as dominant species *Artemisia tridentata* ssp. *tridentata*, *Chrysothamnus nauseosus* ssp. *consimilis*, *Sarcobatus vermiculatus*/*Elymus cinereus* (Tables 2 and 3, Fig. 8). This is a plant community that should not exist because the autecology of the woody dominants is in apparent opposition to each other. *Artemisia tridentata* ssp. *tridentata* is probably the most highly evolved taxon of the *A. tridentata* polyploid complex that characterizes the landscape above the maximum level of pluvial lakes in the Great Basin (McArthur and Plummer 1978). It is not considered to be a salt-tolerant species. *Chrysothamnus nauseosus* ssp. *consimilis* is a

morphologically distinct subspecies in a complex group of root-sprouting shrubs (McArthur et al. 1978). The subspecies *consimilis* is the only *Chrysothamnus* of the *nauseosus* group that is found in abundance in saline/alkaline habitats (Roundy et al. 1981). *Sarcobatus vermiculatus* is not competitive in upland nonsaline/alkaline situations, and the soluble salt residue from *S. vermiculatus* litter has been demonstrated to increase the salinity of the surface to the point of excluding reproduction of *A. tridentata* (Rickard 1965).

The distribution of the dominant shrubs is highly variable, with occasional patches containing an equal representation of these three species. Essentially, *S. vermiculatus* and *A. tridentata* represent saline and nonsaline soil extremes, respectively, with *C. nauseosus* ssp. *consimilis* being more or less able to compete in both extremes as long as the water table is relatively shallow. The swirling, apparently meaningless patterns of distribution of the three dominant shrub species in this environment apparently reflect equally complex evolution of salination-desalination of the older lake plain soils.

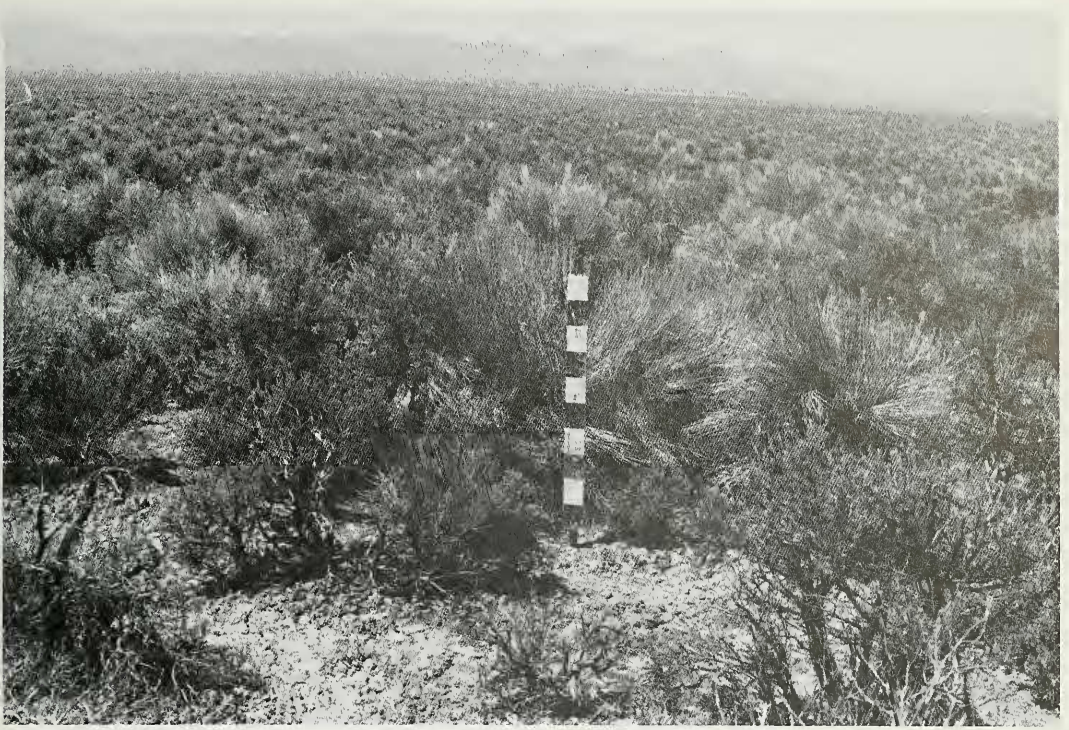


Fig. 8. Most abundant plant community on the older lake plain landforms. Overstory dominants *Artemisia tridentata* ssp. *tridentata*, *Chrysothamnus nauseosus* ssp. *consimilis*, *Sarcobatus vermiculatus*. Understory dominant, which was the mammoth, tufted perennial grass *Elymus cinereus*, is now much depleted by grazing of domestic livestock.

The herbaceous dominant, *Elymus cinereus*, has been greatly depleted by past excessive grazing of domestic livestock (Lesperance et al. 1978). Under pristine conditions, in particularly favorable locations for soil moisture on the lake plain, the annual biomass production of this grass probably reached 2000 kg/ha.

The *Sarcobatus-Atriplex*-dominated plant communities of the older lake plain are similar in appearance and structure to those found on the older Holocene beach (Tables 2 and 3). These xeric communities are associated with areas with deeper water tables that do not fluctuate seasonally.

On the mesic end of the spectrum, several communities exist where the groundwater reaches the soil surface at least sometime during the growing season. In *Chrysothamnus albidus/Puccinella* species, the perennial grasses occur on miniature pedicels. The *Distichlis* meadows are wet to the soil surface relatively late in the season, when water per-

colating through the alluvial fans comes to the surface on the lake plain. This coincides with the phenology of *Distichlis* for summer growth.

In the high water table portion of the lake plain, the soluble salts in the soil profile are largely concentrated on the soil surface by capillary discharge of groundwater.

Located on the far southern extremes of the lake plain are several islands of vegetation completely dominated by *Atriplex nuttallii*. Only a few plants of *Kochia americana* share the communities. The heavily grazed *A. nuttallii* plants are under 10 cm high, so the communities stand out sharply from the 1-m tall mixed shrubs of the surrounding lake plain communities. Other than the very regular lower contact boundary of the soil horizons beneath the *A. nuttallii* communities, there are no obvious soil differences between the *A. nuttallii* islands and the surrounding vegetation.



Fig. 9. Little Hot Springs, Grass Valley, Nevada. Springs support a few square meters of saline/alkaline meadow surrounded by *Sarcobatus vermiculatus* plants located on a peninsula in the center of the playa. The Little Hot Springs is the only source of water for a large area. Mounds were caused by cattle trampling in mud trying to drink. Poles have been placed in caldera of hot springs to discourage cattle from entering.

THERMAL SPRINGS

There are three groups of thermal springs below the maximum level of pluvial Lake Gilbert (Fig. 1, map unit 12). The largest group of springs, the Walti Hot Springs, are on the east central edge of the valley near the maximum level of the lake. The flora around these hot springs has been highly disturbed by agricultural activities, but the occurrence of species such as *Spartina gracilis*, *Juncus balticus*, and the central Nevada endemic *J. longistylis* suggests what the vegetation composition of the shoreline may have been around pluvial Lake Gilbert.

The Little Hot Springs, located in the center of the playa, support only a few square meters of *Juncus-Distichlis* meadow (Fig. 9). Hot Springs Point on the west side of the playa has several thermal springs on large mounds of tufa. Runoff from these springs supports *Distichlis* meadows.

Initially we did not take the temperature of groundwater in the wells when water samples

were obtained. In the second year of sampling, when temperatures were taken, it was determined that on the same day the temperature of the surface of the water table varied by more than 20 C among wells. We considered none of the wells to be located in the thermal springs areas, but slightly geothermal groundwater is widespread on the lake plain.

The almost complete lack of tufa deposits in the basins of pluvial Lake Gilbert is noteworthy considering the thick mantles of tufa deposited in Lake Lahontan (Morrison 1969). The hot springs should have built tufa domes if they were active during the pluvial lake period (Papke 1976).

Plant Communities of Barrier Bar and Lagoon

In the central part of the Valley, south of the playa, extensive areas of *Sarcobatus vermiculatus* communities were delineated. Some of these communities supported cryptogamic crusts in the interspaces between shrubs and stands of *Kochia americana*, which is highly

TABLE 4. Density per m² and projected cover of shrub species in plant communities on the barrier bar and lagoon.

	Barrier beach						Lagoon			
	<i>Sarcobatus vermiculatus</i>		<i>Atriplex confertifolia</i>		<i>Sarcobatus-Kochia americana</i>		<i>Allenrolfea occidentalis</i>		<i>Chrysothamnus nauseosus</i> ssp. <i>consimilis</i> / <i>Distichlis</i>	
	Density m ²	Total cover %	Density m ²	Total cover %	Density m ²	Total cover %	Density m ²	Total cover %	Density m ²	Total cover %
CHENOPODIACEAE										
<i>Allenrolfea occidentalis</i>							0.4	5.2		
<i>Atriplex confertifolia</i>	.2	3.0	1.3	8.0						
<i>Kochia americana</i>					1.8	2.0				
<i>Sarcobatus vermiculatus</i>	.9	11.0	.8	4.3	1.2	16.0	0.2	3.1	0.2	0.4
COMPOSITAE										
<i>Artemisia tridentata</i> ssp. <i>tridentata</i>		T								
<i>Chrysothamnus nauseosus</i> ssp. <i>consimilis</i>		T							0.8	8.4
Totals	1.1	14.0	2.1	12.3	3.0	18.0	0.6	8.3	1.0	8.8

TABLE 5. Frequency (%) and total cover of herbaceous species on the barrier bar and lagoon landforms.

	Barrier beach						Lagoon			
	<i>Sarcobatus vermiculatus</i>		<i>Atriplex confertifolia</i>		<i>Sarcobatus-Kochia americana</i>		<i>Allenrolfea occidentalis</i>		<i>Chrysothamnus nauseosus</i> ssp. <i>consimilis</i> / <i>Distichlis</i>	
	Frequency %	Total cover	Frequency %	Total cover	Frequency %	Total cover	Frequency %	Total cover	Frequency %	Total cover
CAPRIFOLIACEAE										
<i>Cleomella plocasperma</i>	2	T	6	T	2	T				
CHENOPODIACEAE										
<i>Atriplex truncata</i>					6	1				
CRUCIFERAE										
<i>Thelypodium flexuosum</i>	92	2	94	2	88	3				
GRAMINAEEAE										
<i>Distichlis spicata</i> var. <i>stricta</i>	6	T			4	T	100	8	100	38
<i>Elymus cinereus</i>										
		2		2		3		8		38

preferred by domestic livestock. We at first assumed the communities represented a higher level of range condition than was previously observed on similar soils on the older Holocene beach. Distance from water would have limited grazing in these central valley communities (Stewart et al. 1940). A map produced from satellite data showed this area as a separate unit from the remaining lake plain (unpublished data, P. T. Tueller, Division of Range, Wildlife, and Forestry, University of Nevada, Reno). Further investigations revealed a large depression to the south (up watershed). This depression contained reddish colored dunes composed of clay and salt particles. The vegetation on these dunes was almost entirely *Allenrolfea occidentalis*, an extremely salt-tolerant chenopod.

We delineated a large rectangular island about 3.3 by 5 km stretching across the valley from the older lake plain on the east to a 2.5-km-long gravel bar on the west side of the valley. On the north and south sides of the island, escarpments of about 4.5-m height existed. Callaghan Creek was incised into the island with a multiterrace cut about 4.5 m deep. Cowboy Rest Creek incised a channel along the west boundary of the island before continuing on to the playa. We theorized that the island was a result of isostatic rebound following the evaporation of the waters of pluvial Lake Gilbert. Isostatic rebound has been noted for the deeper parts of Lake Lahontan (Mifflin and Wheat 1979). Closer examination suggested that waves driven by northerly winds on the long axis of the valley built a



Fig. 10. *Chrysothamnus nauseosus* ssp. *consimilis*/*Distichlis spicata* var. *stricta* plant communities on the south margin of the *Allenrolfea* dunes in the eroded lagoon. Range poles 1 m divided in dm.

barrier bar across the south end of the basin. A similar bar, on a much smaller scale, is being built across the northern end of the present playa. A third barrier bar may have been built upstream on Callaghan Creek extending out from the most southerly gravel bar (Fig. 1). The only inconsistency with the barrier bar hypothesis for the origin of the central island landform is the lack of a gravel veneer on the bar. The lack of gravel may have been the result of the deep water location of the bar, or the gravel veneer may be buried by subsequent subaerial deposition on the area.

Whatever the origin of the landform, what we identified as the barrier bar served two functions in the evolution of soils and vegetation assemblages in the central valley area. First, the island is elevated above the surrounding landforms, so no overland flow is received from adjacent landforms. The lack of microdrainage patterns and the well-developed cryptogamic crust on the soil surface indicate a very stable surface landscape. Secondly, the island structure apparently blocked drainage from Callaghan Creek to the

central playa, creating a large lagoon. Since the central lake level dropped to the present level of the playa, Callaghan and Cowboy Rest creeks have breached the barrier, allowing erosion of the sediments trapped in the lagoon and the drainage pattern of the entire south end of the valley to erode toward a new base level.

The sediments in the lagoon contain more soluble salts than the surface soils of the present playa. Some soils from the *A. occidentalis* field were 50% soluble salts. Microscopic examination of these soils revealed aggregations of salt crystals that were worn by saltation until well rounded.

The plant communities of the barrier bar and lagoon are characterized by a poverty of species (Tables 4 and 5). South of the *A. occidentalis* dunes in the lagoon area, extensive areas of *C. nauseosus* ssp. *consimilis*/*D. spicata* var. *stricta* plant communities occur (Fig. 10).

Plant Communities of Sand Dunes

Sand-textured soils are very rare in the basin of pluvial Lake Gilbert only 0.3% of the

landscape is covered with sand dunes (Table 1). The well-stabilized dunes are located on an older lake plain surface on the west side of the valley. The sands are not salt affected and support a diverse shrub and herbaceous plant community. Besides the shrubs *A. tridentata* and *S. vermiculatus*, the dunes support *Grayia spinosa* and *Tetradymia comosa*. Several herbaceous species such as the grasses *Oryzopsis hymenoides* and *Sitanion hystrix*, which are characteristic members of plant communities found on alluvial fans, were found on the sand dunes.

Plant Communities of the Alluvial Fans

Over half the area below the maximum level of pluvial Lake Gilbert is occupied by alluvial fans spreading out from the mountain escarpment. Most of this area is covered by various plant communities that are dominated by *Atriplex confertifolia*.

In the southern end of the basin, the pluvial lake was very shallow (less than 7.5 m). The lake sediments are mixed with alluvial material. The *Atriplex confertifolia* plants that dominate this area are less than 0.3 m tall, with total projected crown cover of the shrub around 10% (Fig. 11). Mixed with the *A. confertifolia* are *Sarcobatus baileyi* plants. Where the alluvium has mixed with shallow lake sediments, gravel has sorted to the soil surface to form desert pavement in the interspaces among shrubs. The shrubs are growing on small mounds, from 10 to 35 cm above the interspace surfaces.

Several soils are found in the area dominated by *A. confertifolia*, most of which are Aridisols. The oldest landforms support Haplargids soils. These soils have an argillic horizon. Commonly a calcium horizon has been developed below the argillic horizon. Many of the soils on the pluvial lake sediments are Orthids. These soils commonly have horizons of accumulations of soluble salts and carbonates. The soils do not have argillic horizons.

On the west side of the valley, there is an area of *A. confertifolia/Oryzopsis hymenoides* in apparent high seral status, as a result of protection from grazing by distance from water (Table 6). The density of shrubs here is about the same as in the grazed areas, but the shrub interspaces support a good stand of the perennial grass *O. hymenoides*, with the perennial grass *Sitanion hystrix* found under shrub canopies.

The relationship between *Atriplex* and *Artemisia* communities on the alluvial fans is very complex. The most abundant *A. confertifolia* community in the basin consists of a mosaic of *Artemisia tridentata* ssp. *wyomingensis* in the microdrainageways, with the bulk of the intervening residual soil occupied by *A. confertifolia*.

The alluvial fan consists of a series of fans of differing age. On the southeasterly margin of the valley, *A. confertifolia* extends up the alluvial fans to the mountain escarpment without the intervening *Artemisia*-dominated communities. Along the east central margin of the basin, *A. tridentata* ssp. *wyomingensis* communities extend to the lake plain without intervening *A. confertifolia* communities. This distribution may be due to orographic influences on precipitation, both mountains to the east that accumulate precipitation and mountains to the west that cast rain shadows. Where *A. tridentata* and *A. confertifolia* communities abut each other laterally along the alluvial fans, *A. confertifolia* appears to occupy the older alluvial fan.

The plant communities of the alluvial fans dominated by *A. tridentata* ssp. *wyomingensis* have been described in detail by Cluff et al. (1983). The herbaceous vegetation in the understory of the *Artemisia* community is dominated by the alien annual grass *Bromus tectorum*. Apparently this weed can not tolerate the salt content of the lake plain soils. Ruderal and disturbance weeds in this environment are *Salsola iberica* and *Halogeton glomeratus*.

Plant Communities of Bars

Ranging from the playa to well upon the older lake plain, there are several current bars largely composed of well-sorted gravels. Some of these are 10 km long and rise from the lake plain like railroad embankments (Fig. 12). The typical soils on these bars are Xerollic Camborthids. The most abundant plant communities are dominated by *A. confertifolia/Artemisia spinescens*.

A second form of bars are offshore bars formed between alluvial fans along the margins of the valley. The soils of these bars are similar to those noted for the larger current bars. Wave plunge pits were formed behind these offshore bars. Most of the plunge pits



Fig. 11. *Atriplex confertifolia*-dominated communities at the south end of Grass Valley, Nevada. Range pole 1 m divided in dm.

TABLE 6. Density per m^2 and projected cover of shrub and frequency and cover of herbaceous species in a high condition *Atriplex confertifolia*/*Oryzopsis hymenoides* community.

	Shrub		Herbaceous	
	Density per m^2	Cover %	Frequency %	Total cover
SHRUBS				
Chenopodiaceae				
<i>Atriplex confertifolia</i>	.8	.8		
<i>Sarcobatus baileyi</i>	.2	.2		
Compositae				
<i>Artemisia spinescens</i>	.1	.1		
Total	1.1	11		
HERBACEOUS				
Cruciferae				
<i>Thelypodium flexuosum</i>			9	
Graminaeae				
<i>Sitanion hystrix</i>			27	
<i>Oryzopsis hymenoides</i>			64	
				11

are now filled with silt-textured sediments that are thought to be the result of wind erosion off the playa and subsequent subaerial despoition on the alluvial fans (Young and Evans 1984). The fine-textured deposition

material was reeroded to the natural basins of the plunge pits. We called the filled-in plunge pits lagoons.

The soils of the lagoons are Durorthidic Torriorthents. Some of the lagoons support



Fig. 12. *Atriplex confertifolia*-*Artemisia spinescens* located on the north slope of a large gravel bar on the west side of Grass Valley, Nevada.

stands of *S. vermiculatus*, others *A. confertifolia*. Both species are out of place when the surrounding alluvial fans have *A. tridentata* spp. *wyomingensis* plant communities.

The structure of the surface horizon of the lagoon soils, especially in the interspaces between shrubs, greatly limits moisture penetration into the soil profile. In the spring, after winters with below-average precipitation, there is some moisture available for plant growth in soil profiles of *Artemisia* communities. At the same time soils of the lagoons would be completely dry below the surface.

SYNTHESIS OF DYNAMIC LANDFORMS

The basin of pluvial Lake Gilbert is an elongated bowl filled with stairsteplike terraces of predominately clay-sized particles. Atmospheric drought and reduced osmotic potentials caused by soluble salts combine to limit vegetation cover and subsequent protection from erosion.

Water as a mechanism for erosion is restricted in the basin because of lack of precipi-

tation and the porous nature of the surrounding alluvial fans, which largely absorb runoff from the surrounding mountains and limit surface flow. The fine texture of the lake sediments and the limited vegetation cover promote wind erosion. In a previous study in this lake basin, we documented the erosion and subaerial deposition of fine-textured sediments (Young and Evans 1985).

Although we characterized the role of water erosion as restricted, it must not be overlooked or underestimated. Without periodic moisture events that produce stream flow and/or overland flow to eroded rills, gullies, and washes, the development of cryptogamic crust as now exists on the barrier bar would probably stabilize the interspaces among shrubs and protect them against wind erosion. When sufficient water is available on the lake plain to flow, small streams are faced with extremely flat gradients. In addition, the flat gradients are often interrupted by dunes or offshore bars.

Streams tend to meander on the flat lake plains, with loads of sediment being deposited

in dune basins and plunge pits. Once the barriers to flow are broken by breaching a barrier bar or dune dam, large amounts of sediment are suddenly available for deposition on the next lower level of the playa itself. Two factors complicate this deposition pattern: (1) the sediments that are moving down the levels in the pluvial basins are loaded with soluble slats, and (2) the redeposited sediment often develops vesicular crust, which limits seedling establishment. These erosion processes, which in a humid climate would have proceeded to a new base level milleniums ago, are retarded to an almost imperceptible pace by the current aridity of the basin.

The erosion and deposition processes are proceeding at a microscale in virtually every location in the basin. On the other end of the scale is the 10 km of braided channels above the dune desert, the erosion of which was instigated when the barrier bar was breached.

The basin of pluvial Lake Gilbert, below the maximum lake level, is composed of dynamic landforms evolved toward a new equilibrium. The landform-soil dynamics provide a fertile template to be colonized and dominated by evolving plant species.

LITERATURE CITED

- ANDERSON, D. C. 1978. Cryptogamic soil crusts: factors influencing their development in Utah deserts and their recovery from grazing on Utah winter ranges. Unpublished dissertation, Brigham Young University, Provo, Utah. 81 pp.
- ANONYMOUS. 1951. Soil survey manual. Soil Conservation Service, U.S. Department of Agriculture, Washington, D.C. 504 pp.
- _____. 1975. Soil taxonomy. U.S. Department of Agriculture, Soil Conservation Service. Agric. Handbook 436. U.S. Government Printing Office, Washington, D.C. 754 pp.
- BILLINGS, W. D. 1945. The plant associations of the Carson Desert region, western Nevada. Butler University, Botany Studies 7:89-123.
- _____. 1949. The shadscale vegetation zone of Nevada and eastern California in relation to climate and soils. American Midland Naturalist 42:87-109.
- BLACK, C. A., ED. 1965. Methods of soil analysis. Part I. Physical and mineralogical properties, including statistics of measuring and sampling. Agronomy Publ. 9. American Society of Agronomy, Madison, Wisconsin. 770 pp.
- BOUYOUCOS, G. J. 1962. Hydrometer method improved for making particle size analysis of soil. Agronomy J. 54:464-465.
- CHARLEY, J. L., AND N. E. WEST. 1975. Plant-induced soil chemical patterns in some shrub-dominated semi-desert ecosystems in Utah. Journal Ecology 63:945-963.
- CLEMENTS, F. E. 1920. Plant indicators. Carnegie Institute, Washington, D.C. Publ. 353:1-388.
- CLUFF, G. J., J. A. YOUNG, AND R. A. EVANS. 1983. Edaphic factors influencing the control of Wyoming big sagebrush and seedling establishment of crested wheatgrass. J. Range Manage. 36:786-797.
- CRONQUIST, A., A. H. HOLMGREN, N. H. HOLMGREN AND J. L. REVEAL. 1977. Intermountain flora. New York Botanical Garden, New York. Vols. I and VI.
- EVANS, R. A., AND R. M. LOVE. 1957. The step-point method of sampling—practical tool in range research. J. Range Manage. 10:208-212.
- FLOWERS, S. 1934. Vegetation of the Great Salt Lake region. Botanical Gazette 95:353-418.
- GATES, D. H., L. H. STODDART, AND C. W. COOK. 1956. Soil as a factor influencing plant distribution on salt deserts of Utah. Ecol. Monogr. 26:155-175.
- GOODMAN, P. J. 1973. Physiological and ecotypic adaptations of plants to salt desert conditions in Utah. J. Ecology 61:473-494.
- HOUGHTON, J. G., C. M. SAKAMOTO, AND R. O. GIFFORD. 1975. Nevada's weather and climate. Nevada Bureau of Mines and Geology Special Publ. 2. Mackay School of Mines, University of Nevada, Reno. 78 pp.
- HUBBS, C. L., AND R. R. MILLER. 1945. The zoological evidence. Bulletin of the University of Utah. 78(20): 17-166.
- KEARNEY, T. H., L. J. BRIGGS, H. L. SHANTZ, J. W. MCLANE, AND R. L. PIEMEISEL. 1914. Indicator significance of vegetation in Tooele Valley, Utah. Agric. Res. 1:365-417.
- LESPERANCE, A. L., J. A. YOUNG, R. E. ECKERT, JR., AND R. A. EVANS. 1978. Great Basin Wildrye. Rangeman's J. 5(4):125-127.
- MCCARTHER, E. D., D. L. HANKS, A. P. PLUMMER, AND A. C. BLAUER. 1978. Contributions to the taxonomy of *Chrysothamnus* species using paper chromatography. J. Range Manage. 31:216-223.
- MCCARTHER, E. D., AND A. P. PLUMMER. 1978. Biogeography and management of native western shrubs: a case study, section *Tridentatae* of *Artemisia*. Great Basin Nat. Mem. 2:229-243.
- MIFFLIN, M. D., AND M. M. WHEAT. 1979. Pluvial lakes and estimated pluvial climates of Nevada. Bulletin 94. Nevada Bureau of Mines and Geology, Mackay School of Mines and Geology, University of Nevada, Reno. 57 pp.
- MILLER, R. F., F. A. BRANSON, I. S. MCQUEEN, AND C. T. SNYDER. 1982. Water relations in soils as related to plant communities in Ruby Valley, Nevada. J. of Range Manage. 35:462-468.
- MORRISON, R. B. 1969. Lake Lahontan: Geology of southern Carson Desert, Nevada. U.S. Geological Survey Prof. Paper 401. 156 pp.
- MUNZ, P. A., AND D. D. KECK. 1968. A California flora with supplement. University of California Press, Berkeley, California. 1905 pp.
- PAPKE, K. G. 1976. Evaporites and brines in Nevada playas. Bulletin 87. Nevada Bureau of Mines and Geology, Mackay School of Mines, University of Nevada, Reno. 35 pp.

- RICKARD, W. H. 1965. The influence of greasewood on soil moisture and soil chemistry. *Northwest Sci.* 39:36-42.
- ROUNDY, B. A., J. A. YOUNG, G. J. CLUFF, AND R. A. EVANS. 1983. Measurement of soil water on rangelands. *Agric. Res. Results ARR-W31*. Agricultural Research Service, U.S. Department of Agriculture, Oakland, California. 27 pp.
- ROUNDY, B. A., J. A. YOUNG, AND R. A. EVANS. 1981. Phenology of salt rabbitbrush (*Chrysothamnus nauseosus* ssp. *consimilis*) and greasewood (*Sarcobatus vermiculatus*). *Weed Sci.* 29:448-454.
- ROUNDY, B. A. 1984. Estimation of water potential components of saline soils of Great Basin rangelands. *Soil Science Society of America Journal* Vol. 48, #3, May-June 1984.
- ROUNDY, B. A., J. A. YOUNG, AND R. A. EVANS. 1983. Surface soil and seedbed ecology in salt desert plant communities. In *The biology of Atriplex and related chenopods*. U. S. Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, General Technical Report, Ogden, Utah.
- SHANTZ, H. L., AND R. L. PIEMEISAL. 1940. Types of vegetation in Escalante Valley, Utah, as indicators of soil conditions. U.S. Department of Agriculture Technical Bulletin 713. 46 pp.
- STEWART, G., W. P. COTTAM, AND S. S. HUTCHINGS. 1940. Influence of unrestricted grazing in northern salt desert plant associations in western Utah. *J. Agric. Res.* 60:289-316.
- STUTZ, H. C. 1978. Explosive evolution of perennial *Atriplex* in western America. *Great Basin Nat. Mem.* 2:161-168.
- WEST, N. E. 1979. Survival patterns of major perennials in salt desert shrub communities of southwest Utah. *Range Manage.* 31:43-45.
- . 1982. Dynamics of plant communities dominated by chenopod shrubs. *International Journal of Ecology and Environmental Sciences* 8:73-84.
- WEST, N. E. 1983. Intermountain salt desert shrublands. Pages 375-397 in N. E. West, ed., *Temperate deserts and semi-deserts. Ecosystems of the world*. Elsevier Scientific Publ. Co., Amsterdam. Vol 5.
- WHITE, W. N. 1932. A method of estimating groundwater supplies based on discharge by plants and evaporation from soil. U.S. Geological Survey, Water Supply Paper. 659(A):1-105.